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Intramolecular Excitation Transfer: a Spectroscopic Study of a Series of Neuroleptic Derivatives of para-Fluorobutyrophenone

CORINNE THIERY

Service de Biospectroscopie
Institut de Biologie physicochimique
13 rue Pierre Curie, Paris, France

ABSTRACT

A spectroscopic study of a series of neuroleptic derivatives (AB), using absorption, fluorescence, phosphorescence, and electron spin resonance (ESR) techniques, indicates the occurrence of an intramolecular energy transfer from chromophore B to chromophore A (para-fluorobutyrophenone) separated by methylene groups–$(CH_2)_3$. The experimental evidence may be summarized as follows: Hyperchromic and bathochromic effects on the lowest energy band of the absorption spectrum of AB compared to that of the equimolar solution (A + B). Efficient quenching (about 80%) of the fluorescence of component B in the AB derivatives, but not in the equimolar solution (A + B). The phosphorescence of AB is characteristic of chromophore A even when the initial excitation is localized on chromophore B, which has the highest triplet energy level. A signal, not characteristic of either chromophore A or B, is detected in AB by phosphorescence and ESR techniques when AB is excited between 300 and 350 nm. These spectroscopic differences observed between the behavior of solutions AB and equimolar solutions (A + B) indicate an interaction between the two isolated chromophores of the derivative AB; such an interaction may involve a nonplanar conformation of the derivative AB.

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INTRODUCTION

Several authors have already established the existence of intramolecular excitation transfer within model compounds AB consisting of two conjugated rings A and B linked together by an aliphatic [1-10] or a saturated polycyclic [11,12] chain, even a rigid frame [13-18]. Here we present some results obtained on a series of such molecules often used in pharmacology for their neuroleptic properties. Their action mechanism and even their physicochemical properties are not well known; the study of their spectroscopic properties may thus provide some important information. This work is based on the investigation, by different spectroscopic techniques, of the AB compounds as well as of their components A and B separated or mixed together in equimolar solutions.

If the AB spectra corresponded to the addition of the separate spectra of A and B, then the two fractions A and B could be assumed to be electronically independent. On the other hand, any deviation of the AB spectra from the additional ones would indicate an interaction between A and B, and it would favor the hypothesis of an intramolecular complex (especially when the two rings are separated by a long chain). The stereochemical structure of such complexes is worth discussion: It could explain the physiological properties of the AB compounds when in interaction with biological receptors.

EXPERIMENTAL

Experimental Techniques

Absorption. Absorption spectra were recorded at room temperature with a double-beam Cary 15 spectrophotometer. A series of Hellma sample cells, in Suprasil quartz and of different path lengths (1, 5, and 10 cm), were used for the study of very dilute solutions, especially when the compounds were sparingly soluble.

Luminescence. Luminescence spectra were measured with an Aminco-Bowman spectrofluorophosphorimeter equipped with an XY recorder. The intensities of the emission and excitation spectra presented in this article were not corrected. Fluorescence spectra at room temperature were recorded in quartz cells of square section (1 × 1 cm), with four optical windows. Phosphorescence as well as fluorescence measurements at low

temperature were carried out with 3 mm quartz sample tubes directly plunged into liquid nitrogen. The decay time τ of the recorded phosphorescence emission is determined with a Polaroid camera adapted to a Hewlett-Packard 140A oscilloscope (the response time of the instrument was lower than 0.1 sec).

Electron Spin Resonance. The paramagnetic triplet state was studied with a Varian V 4502-13 spectrometer, equipped with an Osram HBO 200 W high pressure Hg lamp. The light was filtered through chemical filters: a 0.25 M nickel sulfate solution and a [1-1] water-acetic acid mixture contained in 1.6 cm length quartz cells; these two solutions eliminate infrared wavelengths as well as solvent damaging uv radiations. The light beam is then focused on the incoming grid of the measurement cavity.

The microwave frequency emitted by the klystron was measured with a Hewlett-Packard 532B counter. The magnetic field was measured directly with the proton NMR probe of a Varian F 8 X fluxmeter. For more accurate measurements, this fluxmeter was associated with a Rochar A 1360 C wavemeter through an especially designed frequency divider (with a reduction factor equal to 1/10): Proton resonance frequencies ranging from 0 to 20 MHz could be measured with this apparatus.

Materials

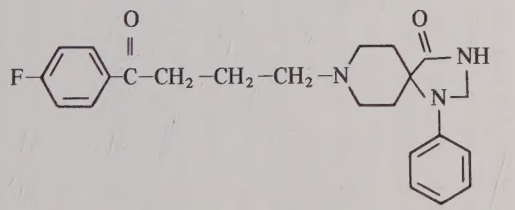
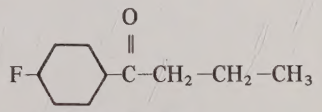
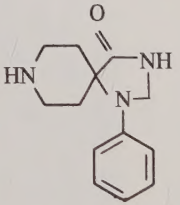
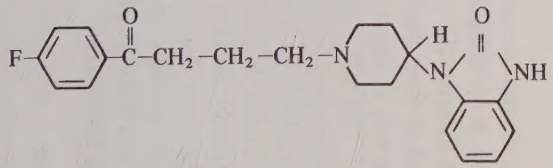
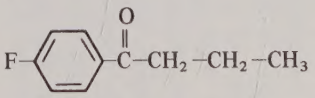
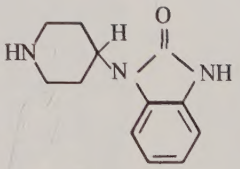
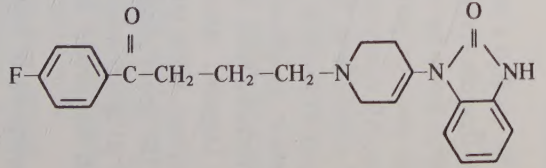
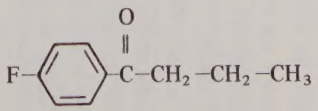
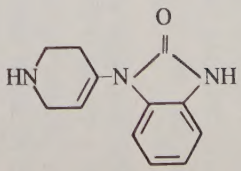
We studied a series of derivatives designated by AB and obtained from para-fluorobutyrophenone A by replacement of one hydrogen atom of the methyl group by various heterocyclic groups B differing from each other in their steric properties and in their degree of conjugation. The formulas of these AB compounds, as well as those of the parent compounds A and B, are presented in Table 1. The AB compounds were kindly supplied by the DRME (Direction des Recherches et Moyens d'essais). As indicated in Table 1, para-fluorobutyrophenone A was purchased from Fluka, and some B fractions from Aldrich; other B compounds were generously given by Dr. Lecolier. Alcohols (EtOH, MeOH) were of analytic grade (Rhône-Poulenc), while tetrahydrofuran was of spectroscopic grade (Merck).

The above products and solvents were used without further purification, but all spectroscopic studies were preceded by preliminary investigations with the solvent alone as blank runs.

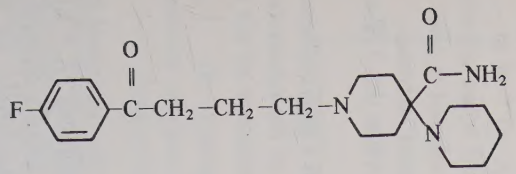
Preparation of Samples

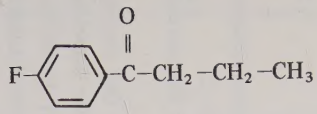
In general, all compounds, except benperidol, are sufficiently soluble in ethanol. The molar concentrations measured at room temperature were,

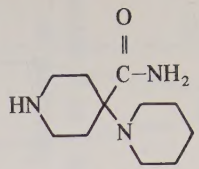
Table 1. Formulas of AB Derivatives with Their A and B Components

Compound	AB	A	B	
Spiroperidol R 5147		 p-fluorobutyrophenone Fluka		
Benperidol R^a 4584				Aldrich 12–9550
Droperidol R 4749				Aldrich K 15

Pipamperone
R 3345

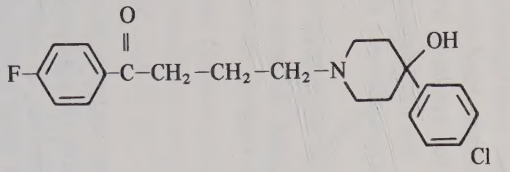


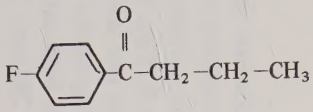


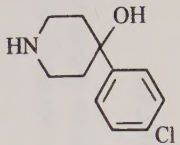


Aldrich
C 302

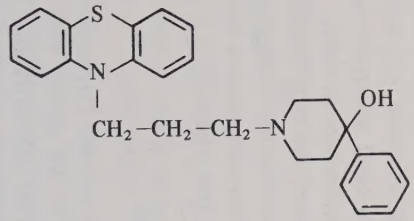
Haloperidol
R 1625

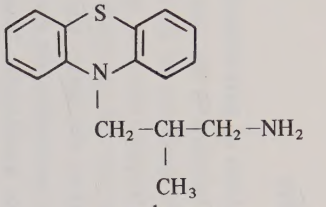




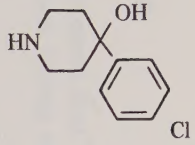


Aldrich
C-66056





RP[b] 6785



Aldrich
C-66056

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[a]R: Janssen-Pharmaceutica.
[b]RP: Rhône-Poulenc.

unless otherwise stated, chosen equal to 2.5×10^{-5} M for optical studies and of the order of 10^{-3} M for ESR studies.

RESULTS

Specific results for each compound are shown in Tables 2 to 7, but we shall first present some general results obtained using the previously described techniques.

Absorption Studies

All the derivatives of para-fluorobutyrophenone show some common characteristics illustrated in the case of spiroperidol in Table 2.

The absorption spectrum of the equimolar solution (A + B) corresponds to the addition of spectrum A to spectrum B (Figs. 1-3).

If we compare any AB spectrum with the one above for the corresponding (A + B) solution, we obtain the following results: (a) the wavelengths of the absorption maximum are the same in both cases; (b) no difference can be noticed for wavelengths lower than 280 nm; (c) bathochromic and hyperchromic effects may be observed at higher wavelengths ($\geqslant$ 280 nm), where only the A residue can absorb; (d) Beer's law is satisfactorily observed in the concentration range under investigation (4×10^{-6} M to 4×10^{-4} M); and (e) the high wavelength band does shift when solvents of varying dielectric constants are used (for instance, when ethanol is used instead of tetrahydrofuran, i.e., when the dielectric constant increases, then the 312-nm band undergoes an hypsochromic shift while the 320-nm band shows a bathochromic shift).

The spectrum of the only compound not derived from a butyrophenone but from a phenothiazine is identical with the spectrum of the equimolar solution of its two components which suggests the independence of the absorbing systems (see Table 7).

Emission Studies

The effect of possible intermolecular interactions may be eliminated by the comparison of AB spectra with those of equimolar solutions (A + B) studied at different concentrations; however, in order to avoid a quenching of the emitted intensity resulting only from a concentration effect, we have carried out in each case a preliminary study of the emitted intensity as a function of concentration.

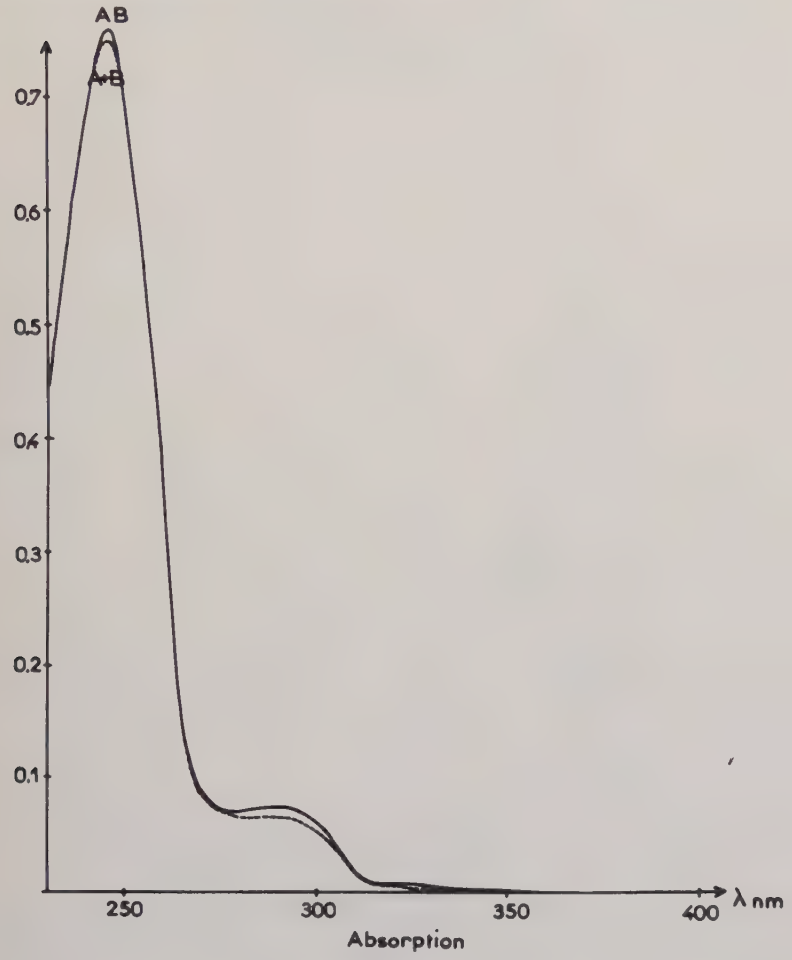


Fig. 1. AB: Spiroperidol (concentration 8×10^{-6} M $l.^{-1}$). A + B [1-1]: Equimolar solution in ethanol of components A and B of spiroperidol (concentration: 1.6×10^{-5} M $l.^{-1}$; path length, 5 cm).

Fluorescence Studies. The following observations were made at room temperature as well as at 77°K: (a) para-fluorobutyrophenone does not fluoresce; (b) the B fractions, except the B residue of pipamperone, show a strong fluorescence; and (c) the fluorescence spectra of the AB compounds are located at the same wavelengths as those of the B fractions [or of the

corresponding (A + B) fractions], but their intensities vary between 10 and 20% of the intensity of the isolated fractions.

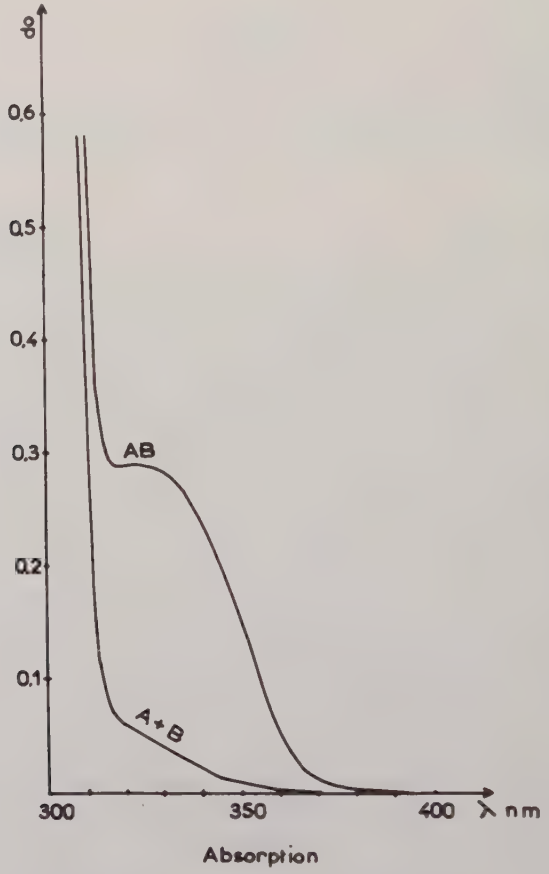


Fig. 2. AB: Spiroperidol (concentration: 10^{-4} M $l.^{-1}$). A + B [1–1]: Equimolar solution in ethanol of components A and B of spiroperidol (concentration: 2×10^{-4} M $l.^{-1}$, path length; 10 cm).

Furthermore, excitation spectra of spiroperidol AB and of the equimolar solution (A + B) of its components can be easily compared in Fig. 4. The AB spectrum shows a significant decrease of the excitation intensity at 295 nm (where both fractions A and B absorb); such an effect is noted in all AB derivatives in which the B fractions may be selectively excited (spiroperidol, benperidol, and droperidol).

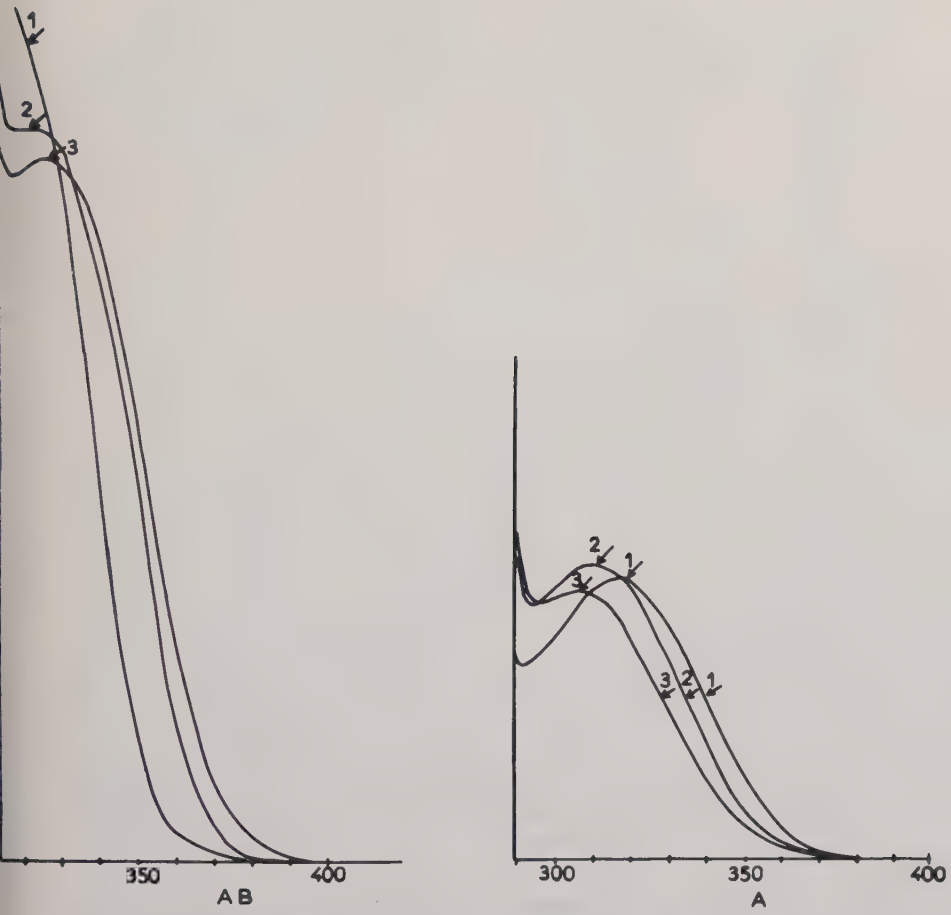


Fig. 3. AB: Spiroperidol. A: para-Fluorobutyrophenone. Solvents: 1. tetrahydrofurane (THF); 2. ethanol; and 3. ternary: methanol, ethanol, water [55:25:20].

Similarly, the two A and B fractions of the derivative 1053 of the phenothiazine are fluorescent and each may be selectively excited: The emission from B overlaps exactly the excitation of phenothiazine A, which, in this AB derivative, is the only fluorescent fraction.

Phosphorescence Studies. All AB compounds are phosphorescent. para-Fluorobutyrophenone, present in the five first derivatives, phosphoresces at

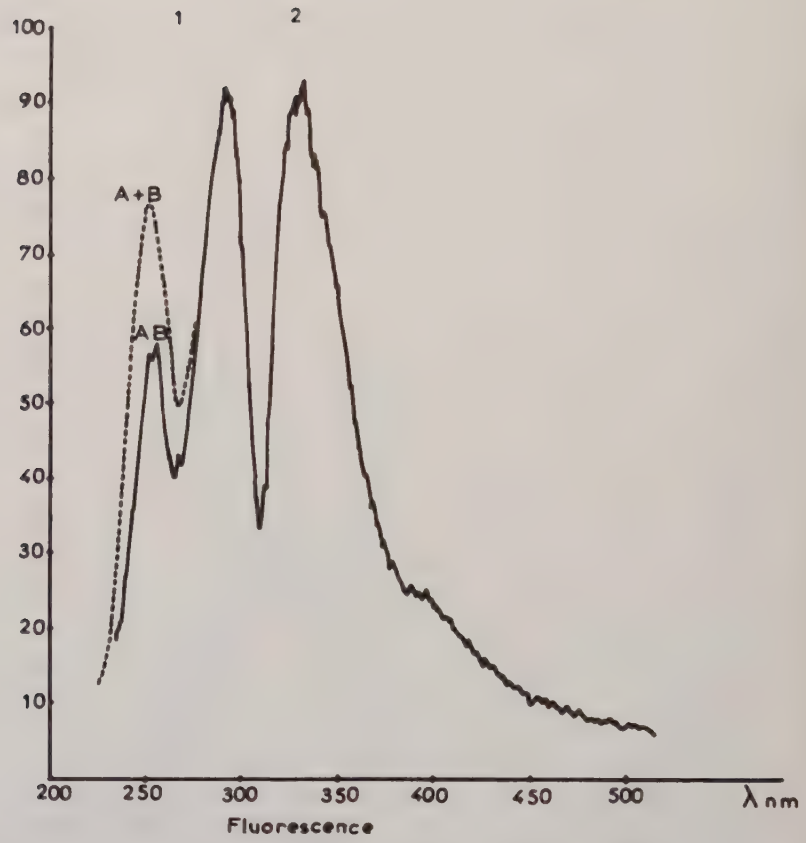


Fig. 4. Solid curve: AB spiroperidol (concentration: 2.5×10^{-5} M $l.^{-1}$, intensity multiplied by 5). Dashed curve: A + B equimolar solution in ethanol of components A and B of spiroperidol (concentration: 5×10^{-5} M $l.^{-1}$). 1. Fluorescence excitation spectrum and 2. fluorescence emission spectrum.

415 nm. Its lifetime is very short (0.004 sec in ethanol according to Calvert and Pitts [19]. The phenothiazine derivative, fraction A of compound 1053, phosphoresces at 475 nm.

All B fractions are also phosphorescent, except the B fraction of pipamperone. Emission wavelengths are usually smaller than 415 nm; we note, however, the weak emission at 425 nm of the B residue of haloperidol.

If we compare the phosphorescence excitation spectrum of spiroperidol with that of the equimolar solution of its components (see Fig. 5), then we notice a decrease of the excitation peak at 240 nm (A and B fractions) with respect to the excitation peak at 285 nm (where only the B fraction absorbs) and a blue shift.

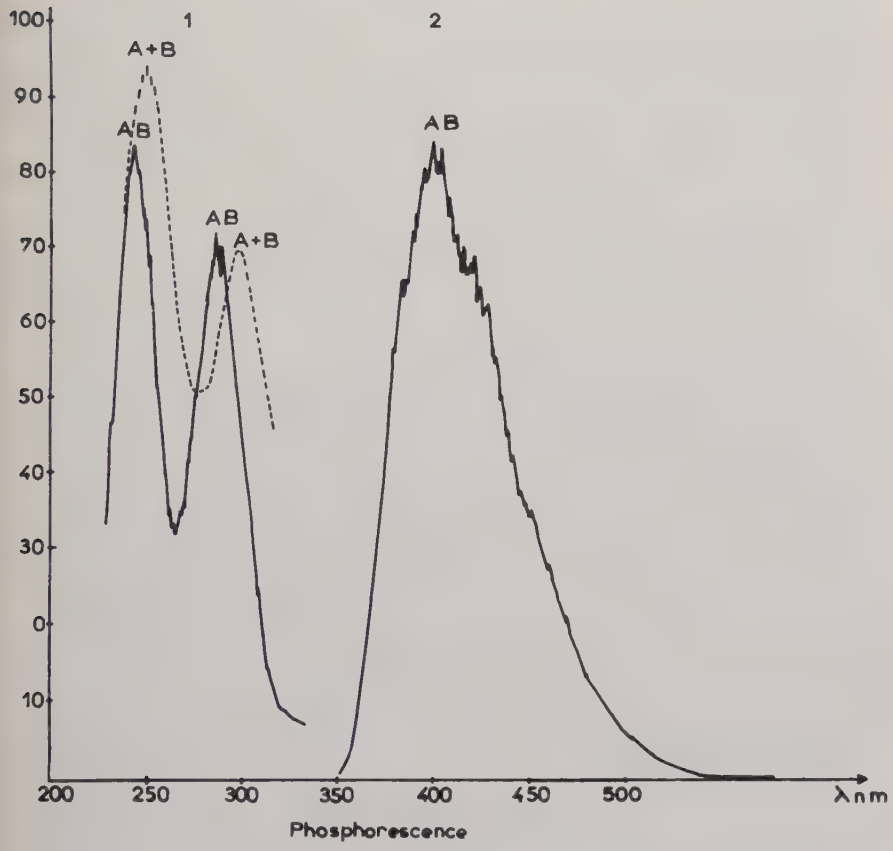


Fig. 5. Solid curve: AB spiroperidol (concentration: 2.5×10^{-5} M $1.^{-1}$ intensity multiplied by 2.5). Dashed curve: A + B equimolar solution in ethanol of components A and B of spiroperidol (concentration: 5×10^{-5} M $1.^{-1}$). 1. Phosphorescence excitation spectrum and 2. phosphorescence emission spectrum.

Moreover, all para-fluorobutyrophenone derivatives show a new phosphorescence emission distinct from those of A and B fractions; it is observed only at high concentration, when the optical density above 300 nm is not negligible; the emission is characterized by the following data:

$$\lambda_{exc} = 330 \text{ nm}; \quad \lambda_{em} = 450 \text{ nm}; \quad \tau = 0.5 \text{ sec}$$

ESR Studies

We have not been able to detect the ESR signal of the triplet state of para-fluorobutyrophenone in ethanol, although the solution presents a very strong phosphorescence. A signal of low intensity was observed in a solvent mixture characterized by a high dielectric constant (MeOH, EtOH, H_2O: 55:25:20). On the other hand, we have been able to record the paramagnetic signals corresponding to the $\Delta m = \pm 2$ transition of the B fractions, either isolated or in the presence of para-fluorobutyrophenone in the (A + B) mixtures. Two exceptions should be mentioned: the B fraction of pipamperone, nonconjugated, and that of droperidol, very sparingly soluble, and showing only a very weak phosphorescence.

The A and B fractions of the 1053 derivative give rise, in the (A + B) mixture, to two partially superimposed signals, which may be distinguished by their different lifetimes.

Except in the case of haloperidol, we did not find the characteristic signals of B fractions in AB compounds. The 1053 compound shows the only typical signal of the phenothiazine fraction.

Furthermore, butyrophenone derivatives AB give a signal which belongs neither to A nor B. By using filtered irradiations (0160 Corning filter), we have been able to show that this particular signal was produced with radiations of wavelengths higher than 300 nm.

In every case, we have measured the value of the resonance field H_{min} and calculated the characteristic parameter D* according to the classical relation [20].

$$D^* = \tfrac{3}{4} [(h\nu)^2 - 3(g\beta H_{min})^2]^{\frac{1}{2}}$$

where ν stands for the radiofrequency equal to 9.120 MHz in this study.

DISCUSSION

First of all, we shall consider the results obtained for para-fluorobutyrophenone, either isolated or as part of the AB molecule. Then, after

discussion of each particular case, we shall try to give a general interpretation of all the results.

Isolated para-Fluorobutyrophenone

The high wavelength absorption band of the isolated para-fluorobutyrophenone, shows the following features: a very small molar extinction coefficient (about 60), a hypsochromic shift with an increase of solvent polarity, and no corresponding fluorescence. These three properties prove the $^1(n,\pi^*)$ character of the first singlet excited state. The strong intensity, the short lifetime of the phosphorescence emission, and the lack of ESR signal in ethanol characterize a $^3(n,\pi^*)$ triplet state. Very polar solvents are known to be able to modify the relative positions of energetically close $^3(n,\pi^*)$ and $^3(\pi,\pi^*)$ state levels. This has been shown for acetophenone and specifically for butyrophenone [21, 22]. This phenomenon probably explains the appearance of the observed paramagnetic signal in a ternary solvent of high polarity.

para-Fluorobutyrophenone as Part of the AB Molecule

In all the AB molecules that we have studied, the phosphorescence of para-fluorobutyrophenone A is not modified by the presence of the B substituent. On the other hand, the singlet excited states of the AB molecules show the following new features.

Solvent shifts as a function of the polarity prove the $^1(\pi,\pi^*)$ character of the high wavelength absorption band, while the same band in the isolated A molecule corresponds to a $^1(n,\pi^*)$ state (see Fig. 3).

A selective excitation of AB in this $^1(\pi,\pi^*)$ band gives rise to a phosphorescence emission with a rather long lifetime characteristic of a $^3(\pi,\pi^*)$ state, and in ESR, to a signal, the D* parameter of which also corresponds to a $^3(\pi,\pi^*)$ state. Those two new $^1(\pi,\pi^*)$ and $^3(\pi,\pi^*)$ excited states in the AB molecule led us to the following hypotheses:

The existence of an impurity, introduced in all AB derivatives; thin layer chromatography tests have been carried out in Dr. Lecolier's laboratory on spiroperidol, droperidol, and haloperidol samples, which have proven their homogeneity. The only product used during the synthesis of A and B, and capable of substitution in AB in a nonmeasurable and yet sufficient quantity to give possible spectral effects, is para-fluorobutyrophenone chloride; but the emission spectrum of this compound cannot be distinguished from that of para-fluorobutyrophenone.

The formation of aggregates is improbable since concentration used in

emission spectroscopy is very low (10^{-4}-10^{-6} M) and since in absorption spectroscopy Beer's law is verified over the entire concentration range which has been considered.

A rapid photochemical degradation could also occur, but such a reaction is not probable since a continuous 30-min irradiation in the AB absorption wavelengths does not produce any modification of the spectrum.

Several authors have found similar results in absorption spectroscopy [5-7, 10] as well as in emission spectroscopy [10]. Shifrin, then Breen and Keller have assumed the formation of a "charge transfer complex" characterized by an absorption band close to the visible and by a typical fluorescence emission. It would be difficult to make the same assumption here since we have observed the same phenomenon for all **AB** compounds even on pipamperone with a nonconjugated **B** fraction, which makes the formation of a charge transfer complex unlikely.

In accordance with Lamola's conclusions, we infer that the effects observed in absorption spectroscopy (in his experiments as well as in ours) may be attributed to the existence of an electronic delocalization of the excitation in the molecule. This delocalization depends effectively on the geometry of the molecule but cannot lead to precise conclusions on it.

In emission spectroscopy, the question of the new phosphorescence band is still unresolved; the existence of a possible impurity is not excluded.

We shall now consider separately the AB compounds; as we shall see, these results can be interpreted by an excitation transfer within the molecule, from one fraction to the other.

Spiroperidol

Results concerning spiroperidol are shown in Table 2 and in the energy diagram of the A and B chromophores in Fig. 6. The 80% fluorescence quenching of B in AB may result either from a nonradiative deactivation process or from a partial transfer from a singlet level of B to a singlet level of the nonfluorescent A residue. [A does not fluoresce as a consequence of the high yield (close to 1), of the intersystem crossing process between the singlet and triplet (n,π^*) states.]

We may consider two kinds of transfer: A partial transfer at the level of the first excitation band of AB (247 nm), which results from a large overlap of the excitation bands of A (242 nm) and B (250 nm); this transfer could contribute to the depopulation of the lowest singlet level of B (293 nm). A partial transfer from this last level (293 nm) to the lowest singlet level

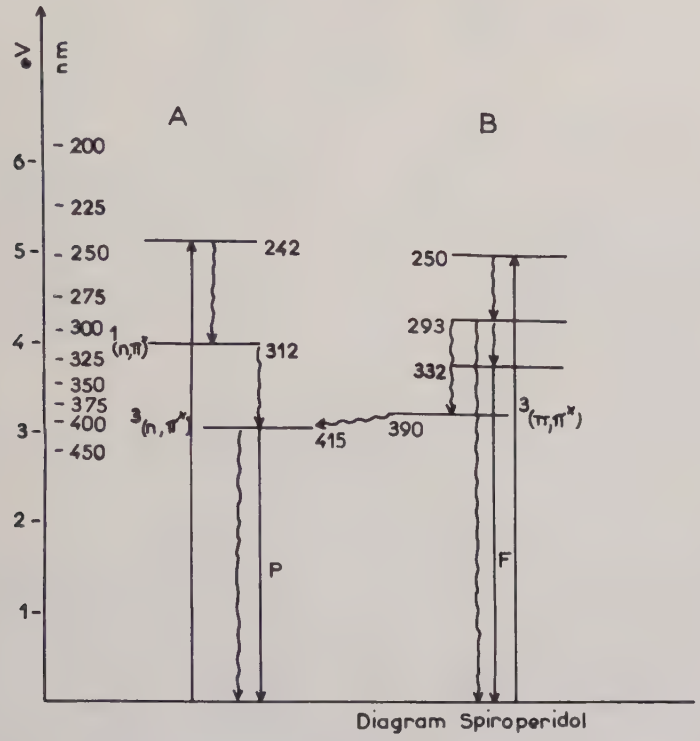


Fig. 6.

of A (312 nm): this transfer is probably less important because of the very small extinction coefficient of the latter band.

The difference between the excitation spectra of AB and (A + B), leading to fluorescence emission as well as to phosphorescence emission, suggests that the first process is the most efficient one and also indicates that a pure nonradiative deactivation cannot entirely explain the observed phenomenon.

The fact that the only recorded AB phosphorescence coincides with a somewhat exalted A phosphorescence supports the existence of a total transfer from the B excited triplet state to the A excited triplet state, since the first (390 nm) lies at a higher energy than the second (415 nm).

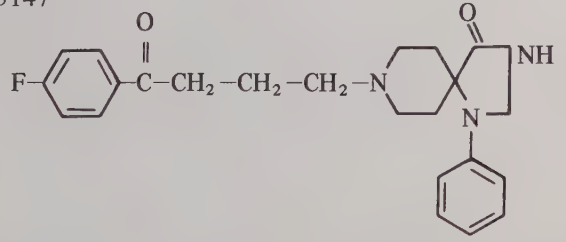
Benperidol and Droperidol

Tables 3 and 4, as well as the diagrams given in Fig. 7, lead to a similar interpretation; however, we should notice the relative importance of the high

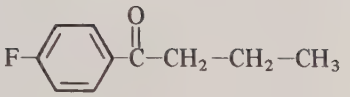
Table 2. λ, λ_{exc}, and λ_{em} Wavelengths of Maxima on Absorption, Excitation, and Emission Spectra[a]

AB
Spiroperidol
R 5147

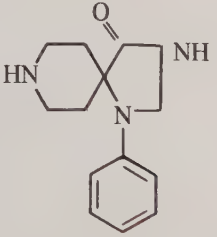
AB:



A:



B:



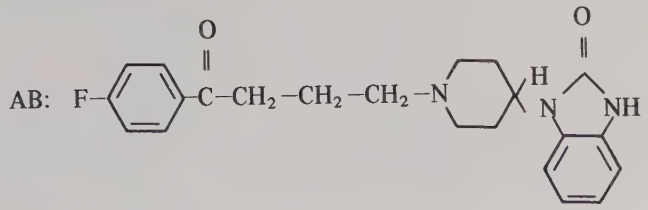
Compound	Absorption λ (nm) (±1 nm)	Fluorescence λ_{exc} (nm) (±5 nm)	Fluorescence λ_{em} (nm) (±5 nm)	Fluorescence I_{rel} (± 10%)	Phosphorescence λ_{exc} (nm) (±5 nm)	Phosphorescence λ_{em} (nm) (±5 nm)	Phosphorescence τ(sec) (±0.2)	EPR I_{rel} (± 10%)	EPR H_{min} (gauss) (±3 g)	EPR $D^*(cm^{-1})$ (±0.001 cm^{-1})
A	242,312	–	–	–	250,(270)	415	<<0.1	100	–	–
B	250,293	255,293	332	100	270,310	390	2	100	1430	0.125
A + B	245,293,312	255,293	332	100	250	410	<<0.1	100	–	–
[1–1]					250,295	390	2	100	1430	0.125
AB	247,293,328	255,293	332	20	240,285	410	<<0.1	250	–	–
					330	450	0.5	25	1540	0.095

[a]( ), shoulder; I_{rel}, relative intensity of emissions (arbitrary unit); τ, decay time; H_{min}, H minimum, resonance field; and D*, zero field splitting parameter.

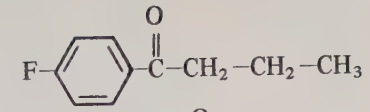
Table 3. λ, λ_{exc}, and λ_{em} Wavelengths of Maxima on Absorption, Excitation, and Emission Spectra[a]

Benperidol
R 4584

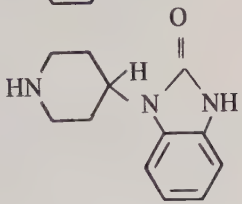
AB:



A:



B:



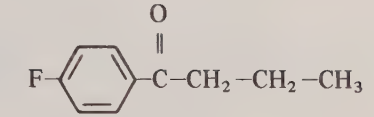
Compound	Absorption λ (nm) (±1 nm)	Fluorescence λ_{exc} (nm) (±5 nm)	Fluorescence λ_{em} (nm) (±5 nm)	Fluorescence I_{rel} (± 10%)	Phosphorescence λ_{exc} (nm) (±5 nm)	Phosphorescence λ_{em} (nm) (±5 nm)	Phosphorescence τ(sec) (±0.2 sec)	Phosphorescence I_{rel} ±10%	EPR H_{min} (gauss) (±3 g)	EPR D^*(cm^{-1}) (±0.001 cm^{-1})
A	242,312	–	–	–	250, (270)	415	<<0.1	100	–	–
B	230,282,(290)	285	325	100	290	375	3.3	130	1405	0.133
A + B [1 - 1]	233,(240),282,(290) 312	285	325	100	250	415	<<0.1	100	–	–
					285	368	3.3	130	1405	0.133
AB	233,(240),282,(290) 310	285	325	15	250,290	415	<<0.1	250	–	–
					330	450	0.5	25	1540	0.095

[a]See Footnote a, Table 2, for explanation of symbols and abbreviations.

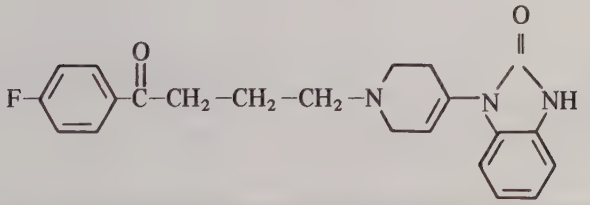
Table 4. λ, λ_{exc}, and λ_{em} Wavelengths of Maxima on Absorption, Excitation, and Emission Spectra[a]

Droperidol
R 4749

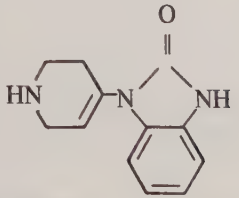
A:



AB:



B:



Compound	Absorption λ(nm) (±1 nm)	Fluorescence λ_{exc}(nm) (±5 nm)	Fluorescence λ_{em}(nm) (±5 nm)	Fluorescence I_{rel} (±10%)	Phosphorescence λ_{exc}(nm) (±5 nm)	Phosphorescence λ_{em}(nm) ±5 nm)	Phosphorescence τ (sec) (±0.2 sec)	Phosphorescence I_{rel} (±10%)	EPR H_{min} (gauss) (±3 g)	EPR D*(cm^{-1}) (±0.001 cm^{-1})
A	242,312	–	–	–	250,(270)	415	<<0.1	100	–	–
B	(228),282,(288)	282	325	100	295	385	–	Feeble	–	–
A + B [1 - 1]	233,(240),282,(288),312	282	325	100	250 295	415 385	<<0.1 –	100 –	– –	– –
AB	233,(240),282,(288),322	282	325	15	265,290 330	415 450	<<0.1 0.5	100 10	– 1540	– 0.095

[a]See Footnote a, Table 2, for explanations of symbols and abbreviations.

wavelength band (282 nm) of the benperidol and droperidol B fractions, which explains why the fluorescence excitation spectrum shows only one maximum.

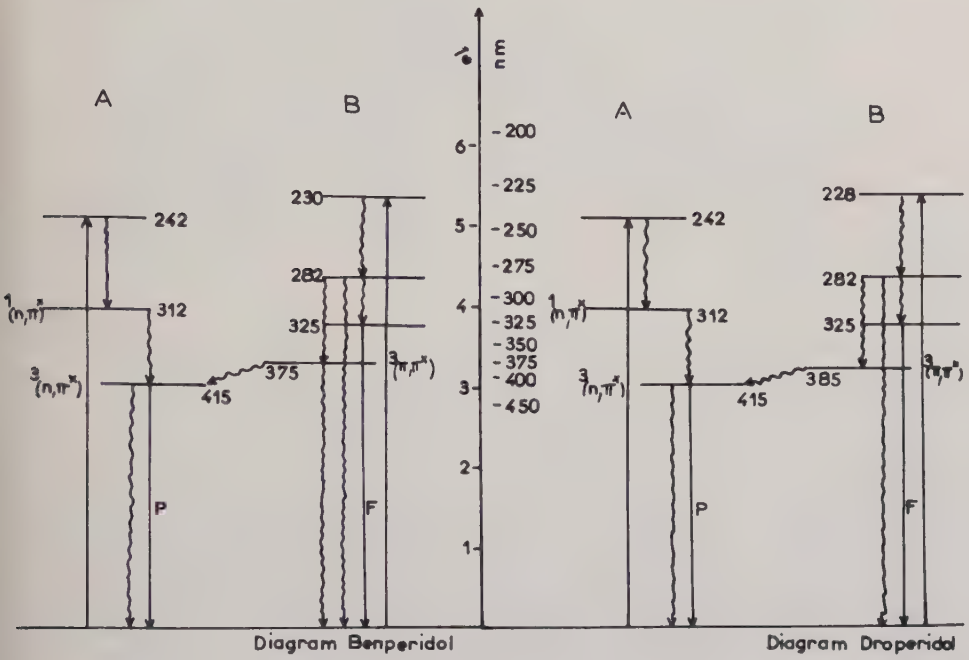


Fig. 7.

A transfer from the singlet level of the B fraction (230 nm) to the A fraction (242 nm) may be assumed without direct proof because of the low sensitivity of the instrument at very short wavelength. The same conclusion holds for a possible transfer from the singlet level of B (282 nm) to the A level (312 nm). However, we have certainly observed a total triplet transfer from B to A, the triplet of which is the only observed one in AB.

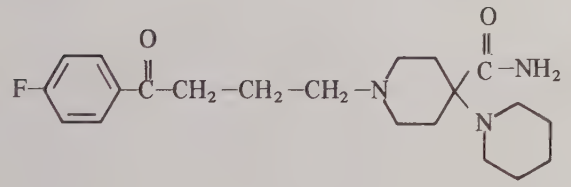
Pipamperone

It may be seen in Table 5 that the nonconjugated B fraction is not excitable in our experimental conditions; in consequence only the characteristics of A are found in the (A + B) mixture as well as in AB.

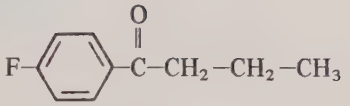
Table 5. λ, λ_{exc}, and λ_{em} Wavelengths of Maxima on Absorption, Excitation, and Emission Spectra[a]

AB
Pipamperone
R 3345

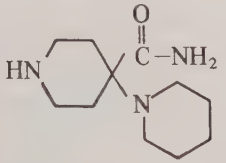
AB:



A:



B:



Compound	Absorption λ(nm) (±1 nm)	Phosphorescence λ_{exc}(nm) (±5 nm)	Phosphorescence λ_{em}(nm) (±5 nm)	Phosphorescence τ (sec) (±0.2 sec)	EPR H_{min} (gauss) (±3 g)	EPR D*(cm^{-1}) (±0.001 cm^{-1})
A	242,312	250,(270)	415	<<0.1	–	–
B	–	–	–	–	–	–
A + B [1 - 1]	242,(312)	250,(270)	415	<<0.1	–	–
AB	242,322	250,(270)	415	<<0.1	–	–
		330	450	0.5	1540	0.095

[a]See footnote a, Table 2, for explanation of symbols and abbreviations.

Haloperidol and the 1053 Derivative of Phenothiazine

Results are summarized in Tables 6 and 7 as well as in Fig. 8. From the phosphorescence spectra of haloperidol and its separate components, we cannot conclude the existence of a triplet-triplet transfer from B to A as in the previous cases; this is because the A and B phosphorescences occur at approximately the same wavelengths with very short and indistinguishable lifetimes, while the phosphorescence intensity of B is very small in comparison with that of A [approximately equal to the phosphorescence of (A + B) or of AB]. On the other hand, the EPR signal characteristic of B is found in AB, which proves that there is no transfer.

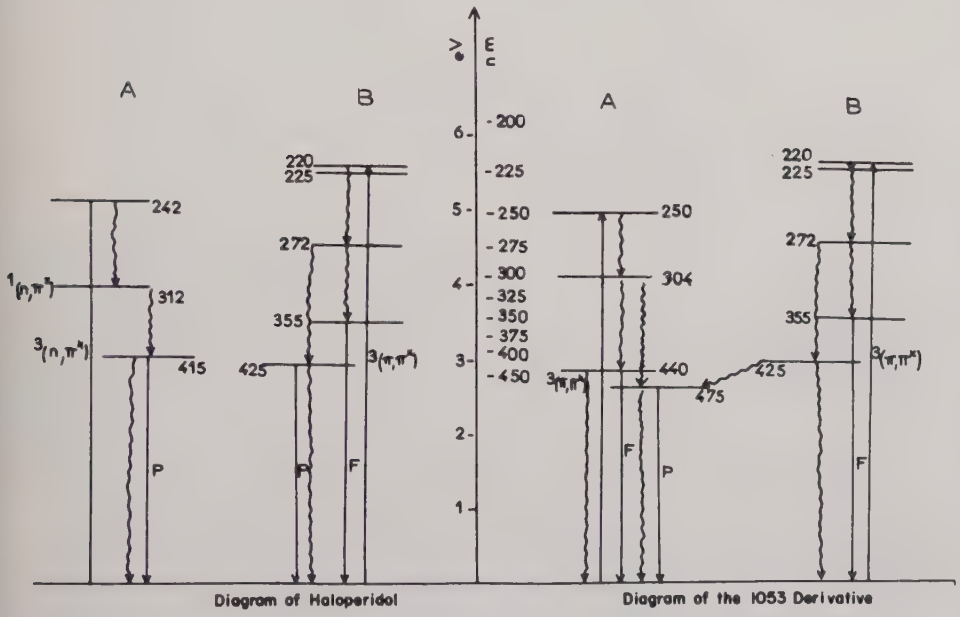
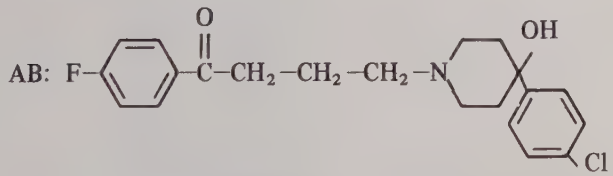


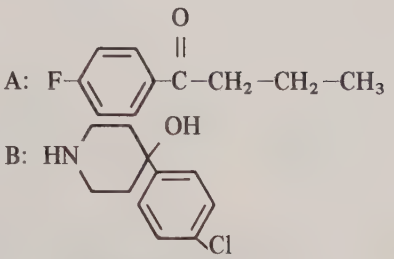
Fig. 8.

The only difference with the various cases which have been studied is the relative distribution of the triplet levels in the A and B fractions since the transfer is observed in the 1053 compound [with the same B fraction but with a different A fraction (phenothiazine with a triplet level at much lower energy; 475 nm)]: The EPR signal intensity of the B fraction of haloperidol which is only slightly quenched when incorporated in the AB

Table 6. λ, λ_{exc}, and λ_{em} Wavelengths of Maxima on Absorption, Excitation, and Emission Spectra[a]

AB
Haloperidol
R1625





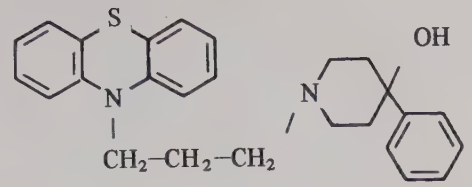
	Absorption	Fluorescence			Phosphorescence				EPR	
Compound	λ (nm) (±1 nm)	λ_{exc} (nm) (±5 nm)	λ_{em} (nm) (±5 nm)	I_{rel} (±10%)	λ_{exc} (nm) (±5 nm)	λ_{em} (nm) (±5 nm)	τ (sec) (±0.2 sec)	I_{rel} (±10%)	H_{min} (gauss) (±3 g)	D^* (cm^{-1}) (±0.001 cm^{-1})
A	242,(312)	–	–	–	245,(270)	415	<<0.1	100	–	–
B	220,225,(272)	290	355	100	250,270	425	–	6	1485	0.107
A + B [1 - 1]	220,225,242, (272),312	290	355	100	245,270	415	<<0.1	100	1485	0.107
AB	220,242,(272)	295	360	10	245,270	415	<<0.1	100	1485	0.107
	320				330	450	0.5	10	1540	0.095

[a]See footnote a, Table 2, for explanation of symbols and abbreviations.

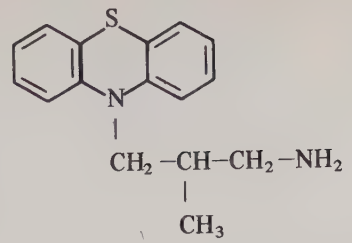
Table 7. λ, λ_{exc}, and λ_{em} Wavelengths of Maxima on Absorption, Excitation, and Emission Spectra[a]

AB

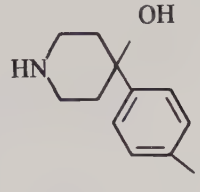
AB:



A:



B:



Fractions near the compounds A and B

Compound	Absorption λ (nm) (±1 nm)	Fluorescence λ_{exc} (nm) (±5 nm)	Fluorescence λ_{em} (nm) (±5 nm)	Phosphorescence λ_{exc} (nm) (±5 nm)	Phosphorescence λ_{em} (nm) (±5 nm)	Phosphorescence τ (sec) (±0.2 sec)	EPR H_{min} (gauss) (±3 g)	EPR $D^*(cm^{-1})$ (±0.001 cm^{-1})	EPR I_{rel} (±10%)
A	250,304	290,350	440	252,305	475	0.2	1456	0.117	100
B	220,(225),272	290	355	250,270	425	–	1485	0.107	10
A + B [1 - 1]	220,(225),254, 304	290,350 290	440 350	Superposition of signals of A and B			Superposition		100
AB	220,(225),254, 304	285,350	440	260,310	480	0.2	1456	0.117	100

[a]See footnote a, Table 2, for explanations of symbols and abbreviations.

molecule proves that the triplet population of B is not greatly modified in AB by the presence of A which could be obtained if there were some noticeable transfers between the singlet levels of A and B.

Thus the case of haloperidol is comparable, by the relative position of the singlet levels as well as by the importance of the fluorescence quenching of B in AB, with all the para-fluorobutyrophenone derivatives which have been studied; it does indicate that the effect of singlet-singlet transfer in the AB molecule is secondary with respect to a nonradiative deactivation process.

We may notice that the total fluorescence quenching of B in the phenothiazine derivative can be easily explained by a trivial reabsorption of the B emission (at 355 nm) by an excitation band of A (with a subsequent reemission at 440 nm). In conclusion, our study indicates the existence of intramolecular energy transfers from the B fraction to the A fraction by partial singlet-singlet transfers (although most of the observed fluorescence quenching is probably owing to a nonradiative deactivation process), and by total triplet-triplet transfers, proved in all cases where they were energetically possible.

CONCLUSION

We have shown in these compounds the existence of important interactions between the two conjugated fractions: These interactions lead to intramolecular energy transfers.

With some or all of the methods reported here, several authors have obtained similar results on different molecules. Some of them have suggested that the two A and B fractions should be favorably oriented in order to give rise to the observed energy transfers [10, 12a,b], assuming the possible existence of true intramolecular complexes resulting from the principle of maximum overlap of the conjugated parts. On the other hand, however, intramolecular energy transfers have been demonstrated in some rigid compounds not allowing any overlap of the conjugated chromophores, but recent publications are somewhat inconclusive on that question [13, 14, and 18, in contradiction with 15, 16, and 17]. We have built molecular models corresponding to our compounds, and we have verified their flexibility, which allows many possible configurations, in particular those where the two chromophores are opposite each other. More precise conclusions require further experimental information, and work is in progress to continue this preliminary study.

ACKNOWLEDGMENTS

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